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Design of Products Through the Search for the Attractor

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ABSTRACT The development of Internet technologies and their application to commerce environments has favored new business strategies for industries. These allow including in the design phase the experience of use that the clients have of the product. However, this new element has not been considered in formal terms. A fundamental problem in product design is that it has not been modeled in mathematical terms, which means that their characteristics do not appear in rigorous and short properties, but in long developments that from an economic point of view maintain their meaning but that from a mathematical point of view are not sufficiently manageable. Therefore, since these properties have not been axiomatically formalized, we cannot work with them mathematically. For this reason, we propose analyzing the design of products through a network and discrete chaos theory perspective, which will allow us to use important mathematical tools such as graph theory and concepts, such as coverage, invariability, orbits, attractors, and the structural function. This paper also draws attention to the importance of circular flow in the general systems theory and its application to the design phase of products. Finally, the Intel case study is analyzed, locating the current attractor and its relationship with the success of the company's products.

INDEX TERMS Coverage, design-build-test cycle, invariability, networks, structural function.

I. INTRODUCTION

Mass customization works generally in economies of scale with relative stable markets. However, at a time when unpredictable market demands are accompanied by almost continuous and fast-paced innovation processes and production sustainability is the new excellence paradigm, the existing automation practices that had for some years supported mass customization processes are starting to subside.

In addition to the technological transformations that are taking place in the transformation of the industry [1], the process of design and development of products in the XXI century involves the realization of a complex set of activities, in which most of the functional areas of the organization must intervene. New paradigm is aimed to continuous and fast-paced innovation processes and production sustainability [2]. Generally this development process is usually divided into five phases or stages:

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1) Identification of opportunities.
2) Evaluation and selection.
3) Development and engineering of the product and the process.
4) Tests and evaluation.
5) Start of production.

The described development process is carried out in an iterative way until reaching the design most suitable to the demands of the consumers. This iterative process is known as the design-manufacturing-test cycle or design-build-test cycle. In each iteration one learns about the problem to be solved and the existing alternatives until the final design is converged and the specifications detailed initially are completed by the search of the attractor (Fig. 1).

The effectiveness of the process of design, development and search of the attractor, will depend not only on the speed, productivity and quality with which each stage of the cycle is carried out, but it will also depend on the number of iterations necessary until reaching the optimal solution.

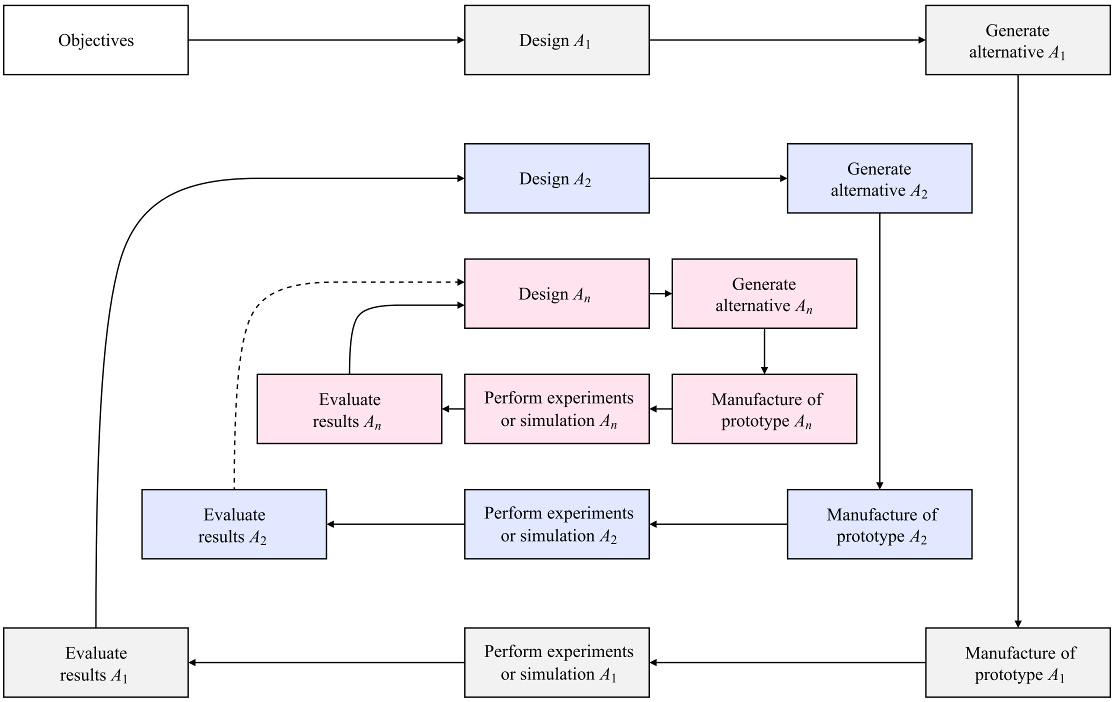

FIGURE 1. Design-build-test cycle.

On the one hand, the rapid development of new technologies has allowed the emergence of new marketing channels, mainly sales through the Internet [3]. These technologies bring the opportunity to industries to reach a greater number of potential customers. On the other hand, new communication technologies allow companies to constantly monitor consumer preferences, so that there are tools to get information about changing market trends [4].

Therefore, thanks to newly emerging technologies, a cycle is generated through which the manufacturer can know the consumer's preferences. It also has new ways of being able to redesign products according to those preferences, potentially reaching any consumer regardless of where they are in the world, far from the limited geographical possibilities of a physical store (see Fig. 2).

Complexity is one of the main factors that penalizes the lead time of product manufacturing systems [5]. In this regard, the impact of the consumer preferences on each cicle could contribute to reduce the level of complexity of the products by achieving a good design. Resolving complexity can be understood as a dynamic process where individuals adopt heuristics to simplify the problem representation [6].

In any case, the design and development process involves a complex set of activities, which will vary depending on the specific project that is faced and depending on the type of innovation to which reference is made and which can be interpreted, as well as many economic systems from the Bertalanffy's General Systems Theory (GST) [7], who defined a system as "a set of elements standing in interrelation between themselves and with the environment", the Circular

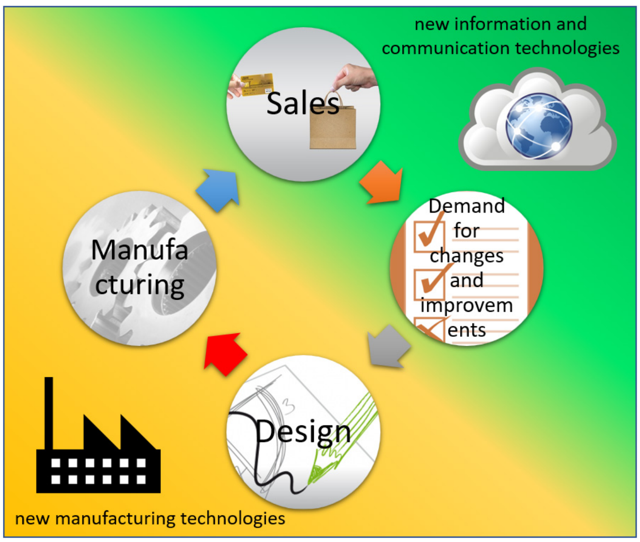

FIGURE 2. It is possible to collect information on the user's requirements and consumer trends using ICTs (information and communication technologies). The user purchases the product through the new sales channels, through which he or she transmits his or her experience, and so the cycle begins again.

Economy [8]–[10], and graph theory, essential for the study of economic problems [11] and in particular in the product design description [12].

However, although the product design process has been analyzed from both a network and economic perspective [13], [14], it has not yet been described by elements relating to discrete chaos theory, namely through the detection of attractors. Therefore, we believe that this new approach discussed in this article could greatly contribute to the research community.

The rationality of the model presented in this paper is clear since there are precedents in this regard. Jiao *et al.* apply chaos theory in the field of fashion design to predict the behavior of market trends for each season [15]. The principles of chaos theory also predict the design of products and supply chains since the demand for a product can be frustrated by the inability of the company to predict and react to various demand models [16].

Chaos theory may explain the apparent disorder in an orderly manner in the purchasing behaviors of many consumers. In particular, Holmström and Hameri analyze consumer responses by looking at the demand attractors of the supply chain [17]. The butterfly effect appears in the positioning of a brand since the economic result is very sensitive to the initial conditions and any novelty causes a big difference in sales. In company product design, the attractor may be determined by factors such as anticipating the market, a technical novelty, a patent, etc., which will determine the product design model towards which companies try to converge. The companies that have the attractor will have a competitive advantage in the market since the attractor will act as a wall that the competing companies will not be able to cross.

In this article, we will try to interpret the design process of a product through the network perspective, making use of concepts belonging to the discrete chaos theory, such as coverage, invariability, structural function, orbits and attractors. We will see the importance that the attractor sets have in the design process, as a fundamental element when determining the success of a product in the market. Finally, we will see the case study of the company Intel, identifying the current attractor of the company and the corresponding success associated with its products.

II. METHODOLOGY

In order to resolve this problem of design of products we shall interpret the circular flow in various interrelated elements of the system: the concept of invariability and coverage in the initial part of the orbit path; and, the concept of attractor in the final part of the system.

The results described below, which are necessary for developing the arguments in this article, have been taken from Lloret *et al.* [18].

In our case, the element set will be formed by the materials, properties and processes used in the design of the products and the relationships will be the transformations and connections of its components in the stages of the product.

The variables (blocks of Fig. 1) can be interpreted as: designing a product, generating the product's alternative, manufacturing the model or prototype, performing experiments or simulations of the prototype, evaluating the results through quality controls or user experiences, etc.

The importance of a *circular flow* (Fig. 3) in the design of a product is that the design of the product is invariant and

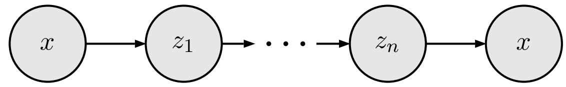

FIGURE 3. **Circular flow.**

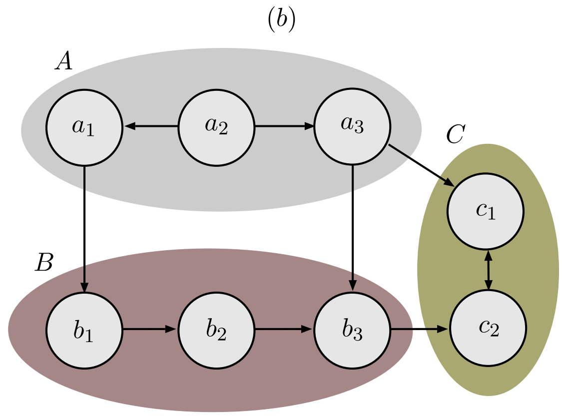

FIGURE 4. **Products design *A* and *B* are not invariant. Product design *C* is invariant.**

therefore it will have an attractor. That is, the research on the design of the product will have reached a degree of satisfaction regarding quality, competition with other companies, customer satisfaction, etc; that will be maximum.

The image of the design product consists of the transformations produced in the product. For example, the image of making a prototype is the experiments and simulations made with it. The image of a variable present in the design process is also known as a *structural function*.

If we consider x_1, x_2, x_3, x_4 are the different transformations of a product and A_1, A_2, A_3, A_4 are the different stages of the product (Identification of opportunities, Evaluation and selection, Development and engineering of the product and process, testing and evaluation), under these conditions, the product determines a circular flow.

The concept of *coverage* reveals basic or primary properties between subsets of the linkage system set of variables, in the neighboring relations between them [19]–[22].

If A determines the set of prototypes used in a product and B determines all the experiments and simulations of the product, if A covers B, then the prototypes cover the experiments and simulations.

The concept of *invariant* set may be interpreted as a set which, while keeping its structure and status, remains constant with respect to any type of relation. For example, if a product design remains unalterable in time, it would be an invariant set (Fig. 4).

As a result, if the transformations of the design of a product determine a circular and invariant flow, it would cover itself.

When the associated structural function iterates indefinitely on any other subset, this gives rise to what we may coin as the term "orbit" of a variable or subset of variables.

The *orbit* of a product design would be determined by its footprint: all designs, prototypes, experiments performed, life cycle analysis, ecological footprint, carbon footprint, etc.

Related with the concepts of orbits and circular flows we have the following properties:

1) If a product design is invariant, its orbit is included in the same product design.
2) If a product design covers itself, its orbit is the same product design.
3) The circular flow of a product design is included in its orbit.
4) If the circular flow of a design product is invariant, it coincides with its orbit.

The objective of any company in the design of its products will be to look for the attractor. The *attractor* would consist of that cyclical set towards which all the variables of the product design process tend. In this case, the attractor would constitute the final loop of the design-build-test process (Fig. 1), formed by the variables: *Design* A_n, *Generate alternative* A_n, *Manufacture of protoype* A_n, *Perform experiments or simulation* A_n and *Evaluate results* A_n. What can be interpreted is that the research on the design of the product will have reached a degree of satisfaction regarding quality, competition with other companies, satisfaction of the clients, etc; that will be maximum while the circumstances do not change.

III. CASE STUDY

The generation of Intel processors with x86 architecture is one of the examples of predominance of a design in the market clearest and durable. However, this architecture is far from being a paradigm of good practices. In fact, two of the most renowned experts in Computer Architecture, Jonh Hennessy and David Paterson quote: ''Whatever the artistic failures of the 80x86, keep in mind that there are more instances of this architectural family than of any other server or desktop processor in the world. Nevertheless, its checkered ancestry has led to an architecture that is difficult to explain and impossible to love'' [23].

The initial success of the x86 architecture is linked to another success: the irruption of personal computers. In 1981, IBM adopted one of the first chips in this family, the 8088, to build on it and launch the most successful line of computers in history: the IBM PC (1981) and the IBM XT (1983). The success of this series was such that, from that moment on, all Intel processors maintained a strict policy of backward compatibility that has continued until today, that is, almost 40 years. This means that any program made for this processor in 1980 can run directly on a current processor in this family. In this sense, we can observe that the technical novelty of backward compatibility has acted as an attractor for the company Intel and has allowed it to avoid competition.

The bet was risky: prioritizing the compatibility of user programs before the cutting edge of technology is a complicated challenge. For a company, 10 years is not much time, and many of them use software that is more than 10 years old. However, in processor technology 10 years is an eternity. Maintaining this backward compatibility means not being able to apply innovative designs to the architecture of the processor and lagging behind the advances that competitors can introduce. And yet Intel triumphed.

In these 40 years of Intel's existence, two milestones made its architecture endure, maintaining the same attractor and avoiding competition:

1) At the end of the 1990s, processors with a reduced instruction set (RISC) dominated performance testing with a wide margin over older processors with a complex instruction set (CISC) of which the x86 family was a clear example. RISCs took full advantage of parallelism at the instructional level and other advantages, and most CISC architecture manufacturers opted to replace them with new (and incompatible) RISC architectures, as was the case with Digital Equipment's VAX computers. In 1997, Intel, beset by poor processor performance statistics and unable to increase the performance of its CISC architecture, opted again for backward compatibility: first, internally translated all its CISC instructions into RISC type but externally offering the same functionality and CISC appearance. This allowed him to take advantage of the instructional parallelism of his competitors as well as make other improvements. Obviously the cost of translating a CISC instruction to RISC is not trivial and the number of transistors your chips increased to accommodate the translator. Luckily, in the late 1990s miniaturization technology allowed many more transistors to be included in chips than in the past so this conversion had little effect on their processors. With all this, Intel here did suffer a major setback: the loss of the embedded processor market. In these small devices, used to control small household appliances (and also in mobile phones), the silicon area is very important as it affects both heat consumption and heat dissipation. From this decision it left this market where pure RISC architectures dominated (and continue to dominate) this type of devices.
2) In 2004 most processor manufacturers were betting on faster and faster processors by increasing the frequency of their clock cycle. Surprisingly, however, Intel cancelled its high-performance processor projects that year and opted for a new strategy: to include more processors per chip instead of making them faster. The decision to move towards parallelism was based on the limits that had been reached in the frequency of operation of the processors that caused them to heat up and fail. No doubt, this was a wise decision that put him back at the forefront of performance, outperforming his competitors. Since then, all manufacturers have introduced multi-core chips into their designs.

Having already seen the context of the case study, let us proceed to the analysis using the proposed methodology. Fig. 5 shows the process of searching for the attractor for the mentioned case of Intel. As we can see, the company starts from initial objectives according to the need to add backward

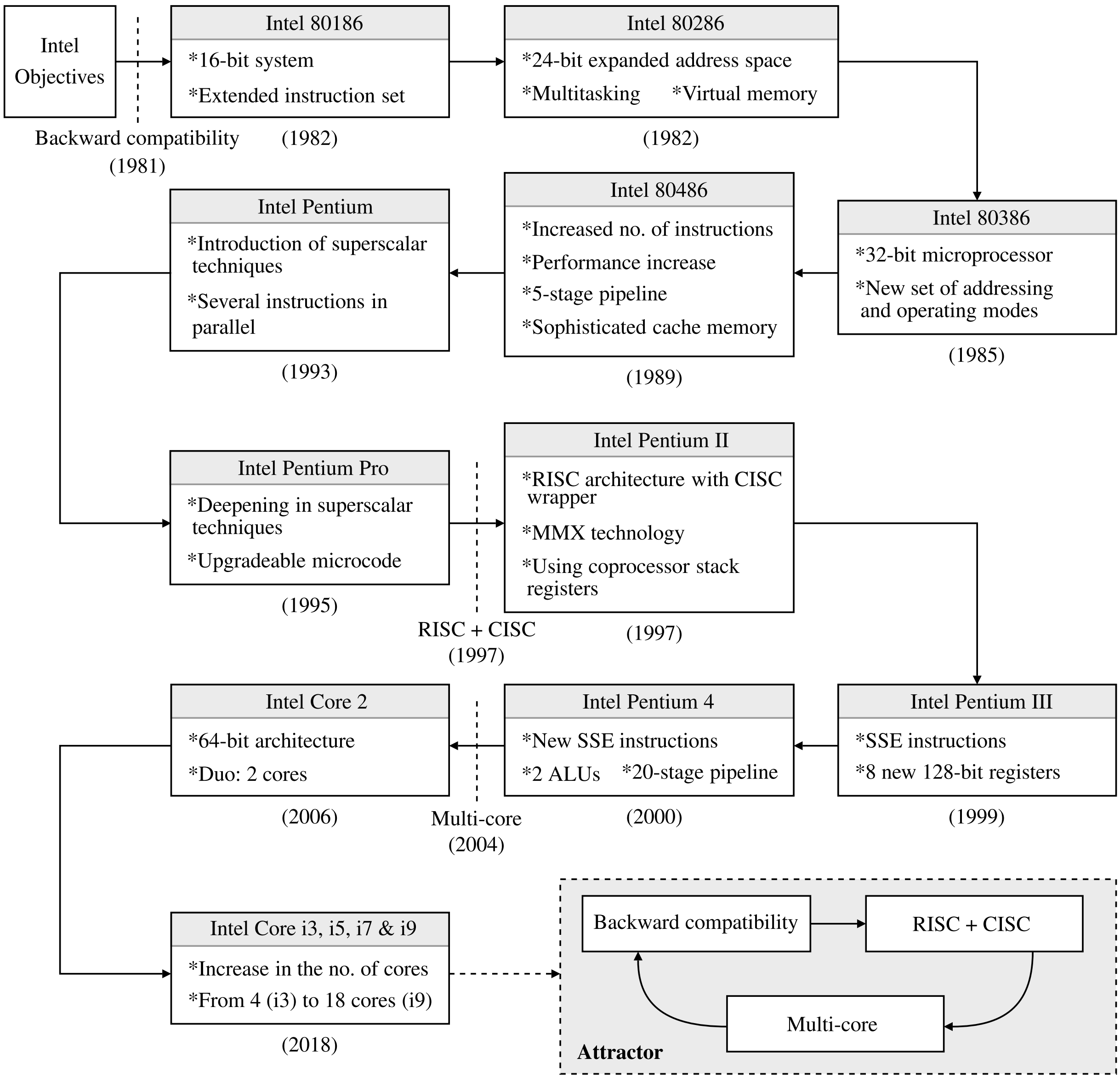

FIGURE 5. **Case study: Searching for the attractor in Intel processor design.**

compatibility in 1981. Subsequently, different models of processors were launched that included this feature: Intel 80186, 80286, 80386, 80486, Pentium and Pentium Pro.

Note that in the blocks of Fig. 5, corresponding to the main models of Intel processors, the upper part shows the name of the model, while the lower part summarizes the main milestones that were introduced in that model. On the other hand, it is also necessary to add that the block of each model would include its stages of design, generation of alternatives, construction of the prototype, simulation and evaluation of results.

In 1997, the specification of the RISC architecture with CISC wrapping was introduced, so that the company began to market different processors that contain this feature, in addition to backward compatibility: Intel Pentium II, III and 4. During 2004, the multi-core feature was added to all processors manufactured since then, including those of the current era: Intel Core 2, i3, i5, i7 and i9.

Therefore, we can observe that, despite the specific features of each processor model launched by the company, we have detected three features that have persisted over the past decades: backward compatibility, RISC architecture with CISC wrapping and multi-core. Thus, the current attractor of the company would be composed by all the design stages of the future processor that includes the three mentioned specifications. This attractor has not only influenced the success of Intel's products but also their differentiation from the competition.

However, we must bear in mind that due to the dynamic nature of the attractors, they may change over time, according to advances in the company's products and characteristics that will endure in the near future.

IV. FUTURE WORK

There are some interesting future works of this approach for addressing the complexity of the design process of products. In this sense, we can distinguish the general and specific lines of future work.

With regard to the general lines of work, first of all, a practical identification of the main involved aspects of an industrial sector should be made in order to codify this approach; secondly, analytical work needs to be made to bring out the relations between the aspects of the industry, and finally; the study and explanation of the results achieved to draw conclusions on practical actions for that industrial sector.

Lastly, we can point out the following specific future lines of work:

- Identification of the main trends in the product design process of a given company.
- Causal analysis of attractors through databases related to the production of a company.
- Automation of the proposed methodology through the implementation of specialized software.
- Study of the success or failure of a product through the analysis of the attractor.
- Locating attractors in the after-sales process, as a tool to quantify customer satisfaction with the product or service purchased.

V. CONCLUSION

The introduction of new ICTs (Information and Communication Technologies) has led to the inclusion in this cycle of one more element: the customer's own opinion. This feedback obtained through company websites or through social networks is cheap, fast and effective since there is almost instantaneous information on the customer's reaction to a new product. The companies incorporate these opinions making them arrive at the design offices and with them to be able to realize products that are in tune with the client. This new snapshot of the design cycle incorporates a further element of complexity that has not yet been analyzed in formal terms.

We performed a mathematical approach of the product design cycle in the context of network theory. An object "as invariant" as the circular flow, opens the doors to interpret the product design. In this sense, the concept of circular flow has begun to play a fundamental role.

The phenomenon of the existence or not of the attractor can determine the final behavior of the product design and we have proven that its appearance comes together once again to the existence of invariant subsets.

The search for the attractor in the design of the products will represent an evaluation of the competing companies in the same market. More specifically, the companies that win this competition are the companies that make attractors appear in the design of their products and that occur in the minimum possible time and in the least number of iterations. The companies affected in this competition will be companies whose product designs do not reach the attractor since that will mean that their designs are not competitive and that they should be designing new prototypes.

Finally, we have been able to contrast this phenomenon with Intel's famous design process, verifying that there is an attractor associated with the success of its products, this being a differential factor that has allowed the company to distance itself from its competition.

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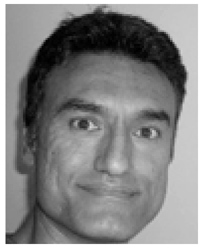

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